EXECUTIVE SUMMARY

This report summarises the results and recommendations of a study to find the next hydropower generation project on the St. Paul and the Via Rivers following on from the commissioning of the Mt. Coffee Hydro Power Plant (MCHPP) in 2017. The overall objective of this Optimization Study is:

> *"To identify the Priority Investment Project (PIP) for power generation in Liberia including priority hydropower projects on the St. Paul and Via Rivers as well as production, storage, and transmission."*

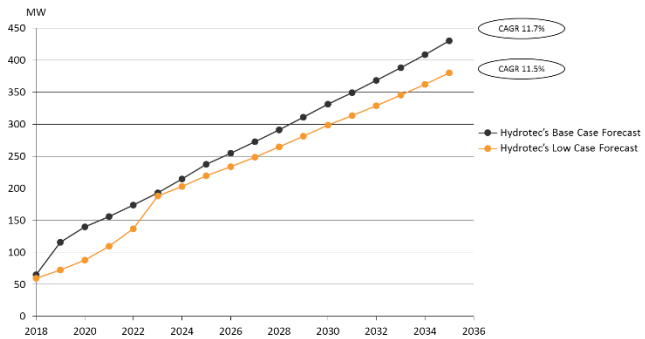
The study has taken into consideration; i) the importance of ensuring low-cost generation also to cover dry-season supply requirements, ii) the potential for cash-generating wet season export, iii) balancing energy security concerns with the benefits offered by regional trade through the nearly completed CLSG line, and iv) the critical importance of a short lead time for the delivery of the selected PIP.

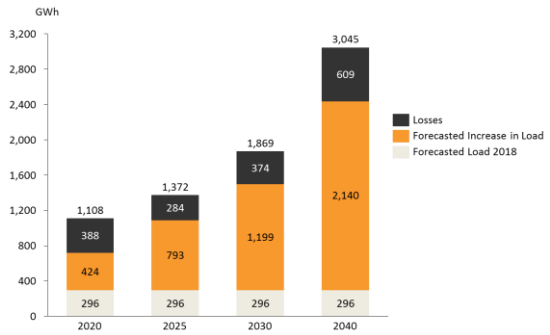
The study has systematically assessed the attractiveness of **all identified sites along the entire St. Paul River basin**, totalling up to 900MW in technical potential (including all possible extensions). The study has consolidated and built upon previous assessments of the river and specifically the Via reservoir. In determining the attractiveness of individual sites and recommending a build-out sequence for the river, the study has considered technical potential, total project costs, potential environmental and social impacts, supply requirements to meet future demand (including dry season) and overall system operations.

As opposed to previous assessments of the Via reservoir, the study recommends that the staged build out of the St. Paul River Basin **starts with the most attractive downstream sites, with Via Reservoir coming in only once the most attractive sites are constructed**. The study demonstrates that this provides both badly needed near-term capacity for Liberia and represents the least cost development path for the sector. Further, with significant uncertainties regarding developments in Liberia and the region, this strategy limits risk, as the Priority Investment Project is considered a "no-regret" investment. That is, the PIP provides low cost near-term capacity while providing a foundation for an economical build out for Via Reservoir. In addition to the most attractive sites on the St. Paul River, the PIP includes a fast-tracking of utility-scale solar. The prioritization of loss reductions and reliable power imports are pre-conditions for the successful implementation of the PIP.

The Challenge: Meeting rapidly growing demand in an affordable way

As illustrated below, assuming aggressive grid expansion and economic growth, it is anticipated that power demand will grow rapidly in the coming years – by more than 12% per year until 2040. In this regard, the Consultant has, in consultation with the client assumed, as the basis for the study, the Hydrotec's (2018) demand projections. This projection includes growth in consumption, development of losses, daily demand profiles, load factors, etc. A fundamental assumption is that all theft and system losses are reduced to a maximum 20% of energy demand by 2026 at the latest.





Towards a Long-term Development Plan for Liberia

Based on anticipated costs of different supply options for the country (hydropower candidates, solar PV, thermal and import/export through CLSG of up to 108MW), a least cost long term development plan (LTDP) has been identified for Liberia, utilizing state-of-the-art optimization tools. The figure below illustrates **the recommended investment sequence to meet rapidly growing demand until 2040**. Some important observations to be had from the figure include:

- The anticipated tripling of demand until 2023/24 leaves Liberia with limited options in terms of meeting demand, especially in the dry season.
- From a least-cost perspective, imports in the dry season play a critical role in terms of meeting demand both in the short- and long-term.
- It is of utmost importance to begin detailed planning for the PIP so as to avoid substantial supply deficits from 2026 onwards.
- By focusing on the most attractive generation sites, planning for Via Reservoir can run in parallel and allow for sufficient time for construction and commissioning later in the planning period.

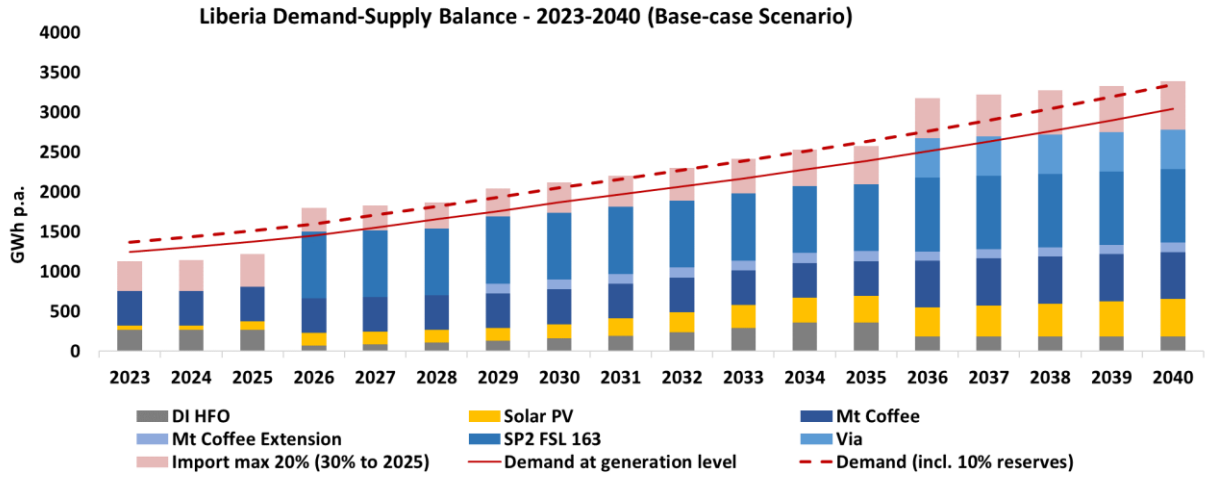


Figure 0-1 Base-case least-cost development path for Liberia (GWh)

The PIP – meeting medium-term supply requirements

As noted above, in the base case, the power demand is expected to grow rapidly in the coming years, and it is important that affordable power is made available in the near-term. As a result of the analysis, the selected PIP consists of the following individual investments and accompanying policy priorities:

1) **An approximate 150MW MUSD 750 hydropower plant** on the St. Paul River (SP2) providing valuable energy, including storage by 2026. Incorporate extra turbine bays into design thereby allowing rapid and cheap increase in generation once regional demand for export warrants the extra investment and /or the commercial model warrants development of the larger SP4 or Via reservoir. This is the proposed primary new development on the St. Paul river for immediate prioritization.
2) **Up to 90MWp of total solar PV capacity** at several sites also representing about MUSD 100 in investment. The capacity installation should start as soon as possible and be phased in over the period. An analysis of the capacity of the grid to absorb the intermittency of the solar PV power should also be prioritized so as to determine the maximum responsible pace for this scale-up. A pilot project of 10-20 MW should be initiated as soon as possible.

3) **A 44MW extension of Mt. Coffee** (2 x extra intakes were incorporated into MCHPP construction). This is a very low cost source of power, but almost entirely for the wet season. This should thus be of high priority with a tentative in service date set at 2029.

Two highly prioritized policy measures are required for the successful development of the PIP:

a. **Loss and theft reductions are of utmost importance**. There is a clear requirement to build on the milestone passing of the power theft amendment. Attracting the level of responsible and manageable funding required for any large domestic generation project will remain difficult or impossible with the current levels of commercial losses standing at 60%.

b. **Firm up power trade options**. In the immediate-term, finalize PPAs with neighbouring countries and industrial off-takers in order to (i) secure dry season supply in the coming seven years and (ii) take the opportunity to sell surplus capacity from Mount Coffee in the short-term. In order to firm up long-term dry season supply at an affordable cost and ensure system flexibility, engage with WAPP partner countries preferably before Liberia is in a deficit situation.

Methodology – how these results were arrived at

The Consultant's team has utilized two modelling tools, which in combination have provided the Client with a highly insightful vehicle for understanding the optimal build out of the cascade model in light of the expected future development of the sector in the four CLSG countries.

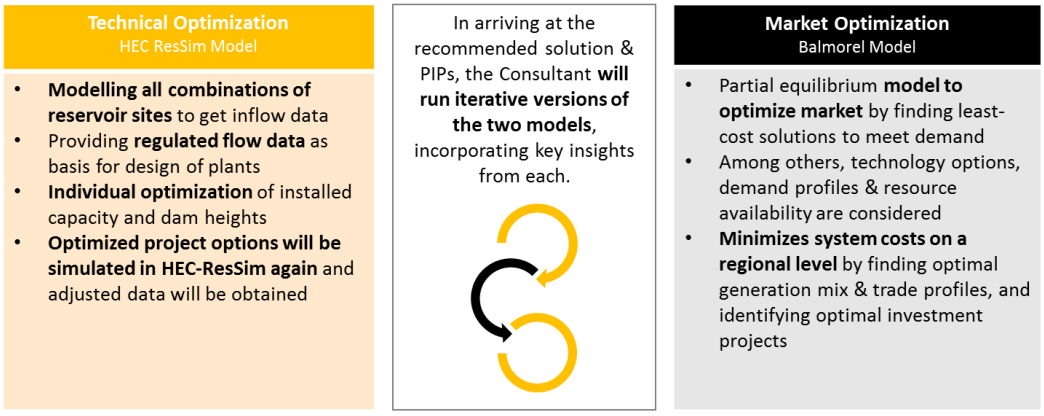


Figure 0-2 HEC-ResSim and Balmorel in successive stages

Optimisation of site locations and dam heights

As described in the following figure, a cascade of 6 different hydropower projects on the St Paul River were identified and their characteristics optimised using the LIDAR terrain map which covers the entire river length. As illustrated in the figure, the candidate sites essentially utilize the entire head of the available river basin.

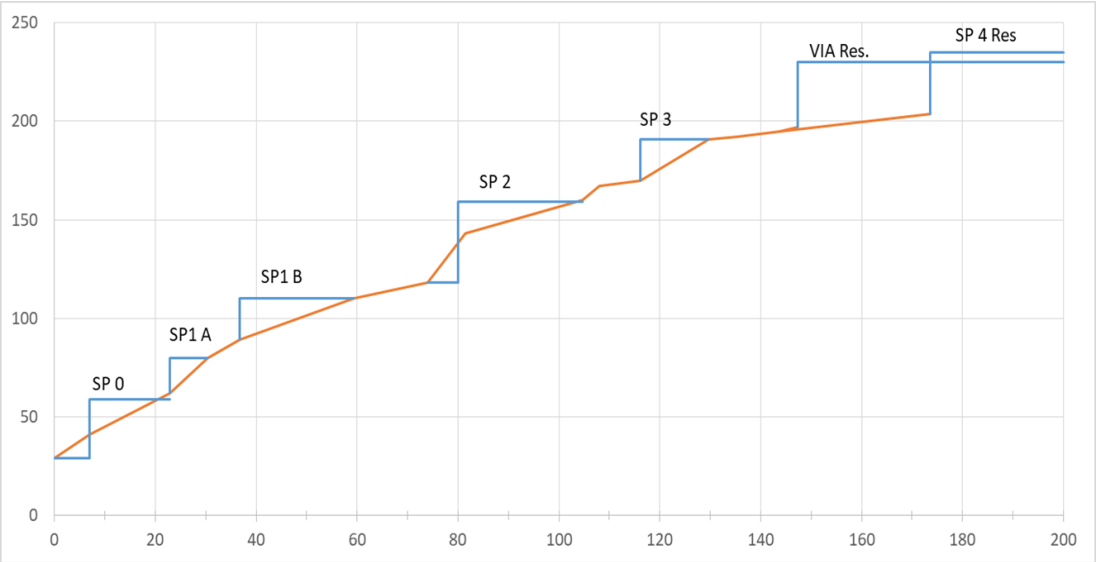


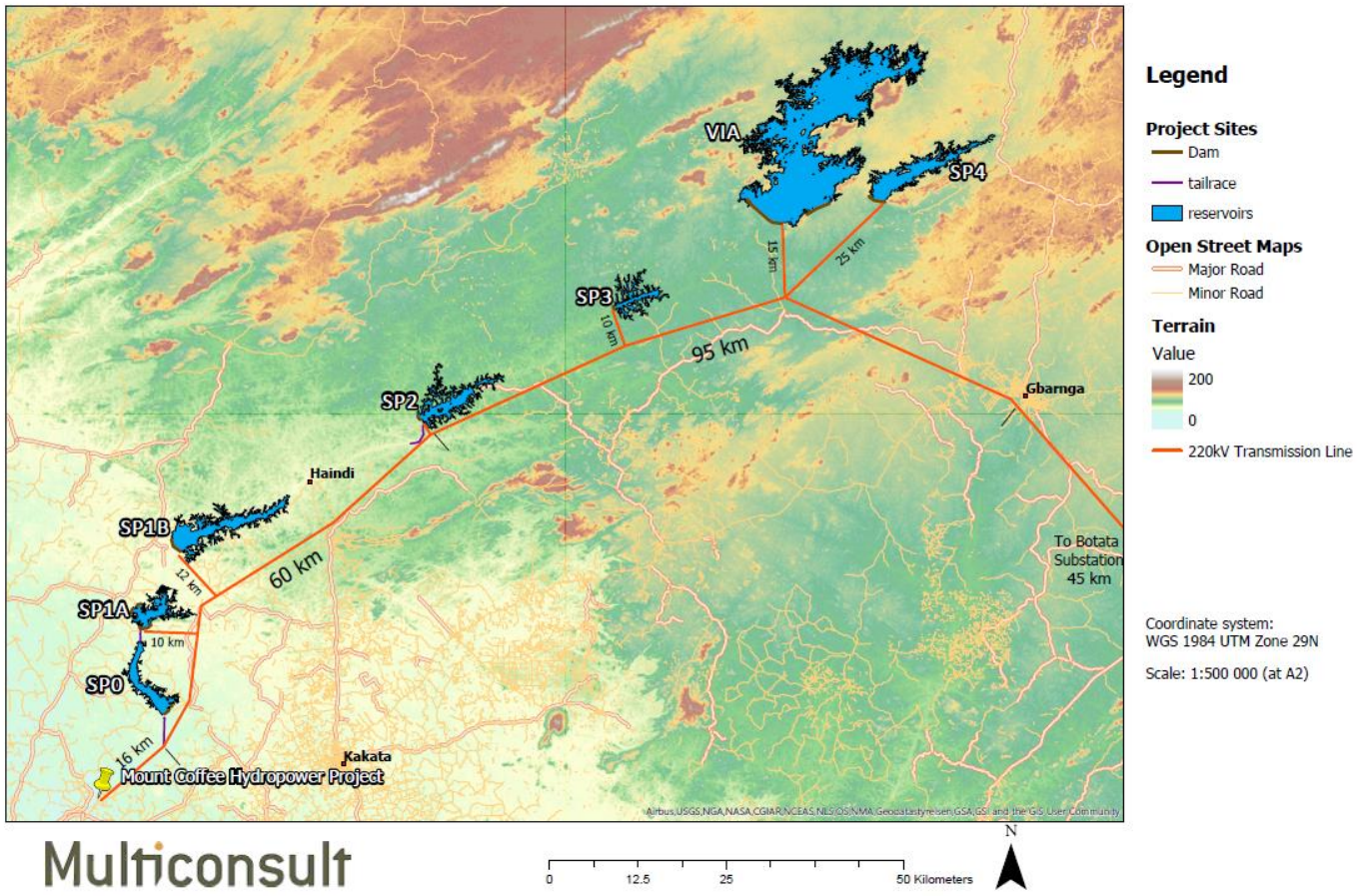
Figure 0-3 Full cascade of candidate hydropower projects along the St Paul river

All SP dams are provided with a reservoir large enough to enable synchronised daily peaking operation. Only Mt Coffee has a limited size of reservoir restricting its ability to provide peaking capacity to the power system. Some of the cascade dams can impound reservoirs large enough to provide varying degrees of regulation, and SP2 is one such dam. As highlighted in the report, a combination and synchronization of hydro and the immediate development of solar generation appears to be a highly attractive option for Liberia now and in the future.

Because of a high concentration of available head, combined with a more compact dam and attractive reservoir site, SP2 hydropower project is recommended as the main component of the priority investment project (PIP). Thus, as confirmed by the optimizations in the report, the selection of the SP2 option would be expected deliver the lowest system energy cost. The proposed FSL reservoir level for SP2 by the Consultant is 163, which provides a storage volume of 310 million m^3, enough to supplement the dry season flows **and maintain continuous output of 40 MW throughout the dry season.** Notably, given the lack of detailed data available for the study, the final optimization of particularly the full-supply-level will need to be more closely considered. Further, as described below, the recommended dam height would imply a required resettlement of 8 500 – 16 600 people.

The Via / SP4 reservoir seems to be better suited as a longer-term project for 15-20 years in the future. Specifically, it should be expected that these reservoir options will become more attractive once more attractive generation downstream sites on the cascade can benefit fully from them. SP2 hydropower site has also been optimized for development in two phases: initially 3 identical Kaplan units with an option to add two more when needed a few years later or when the Via / SP4 option becomes commercially viable. Alternative arrangements using Francis turbines could also be considered.

Figure 0-4 Map showing project locations and impounded areas



The map showing project locations and impounded areas is shown in Fig 0-4 and the detailed overview of the SP2 project is shown in Figure 0-5. To utilise as much as possible of the reservoir, a minimum operating level of 152 has been planned, meaning a maximum of 11 m drawdown during the dry season from January to April. Reservoir operation simulations show the reservoir to normally be drawn down to around 158 before the onset of the flood season begins to refill it, but during dry years the level may approach 152.

Environmental and Social Aspects

This Optimization Study has assessed the main environmental and social (E&S) risks and impacts identified for each of the candidate project sites, and this screening has been used to inform the optimization process. The present report is based on previous reports & field visit by Hydrotec and complementary fieldwork conducted in June/July 2019, which included a rapid biodiversity assessment of the Via Reservoir area, and consultations with the Environmental Protection Agency and other biodiversity stakeholders in Monrovia. It also expands the analysis of resettlement and social safeguards impacts at the PIP location (SP2 dam and reservoir site). Finally, it provides recommendations on environmental and social mitigation measures at each of the candidate hydropower sites, including SP2 and Via&SP4.

While the environmental risks and impacts are categorised as high for the Via reservoir, **the impacts of the recommended PIP of SP2, at the FSL of 163, are mainly categorized in the low to medium range**, and are expected to be possible to mitigate. However, the introduction of seasonal regulation with the larger reservoir size at FSL 163 does carry greater impacts on resettlement and land compensation and impacts on fish and prawn species despite mitigation in design of passages with environmental release flows. The figure below summarizes the implications of the different dam options for SP2.

Table 0.1 Total Estimated Social Safeguards Mitigation Costs for the Various Alternatives Evaluated for SP2.

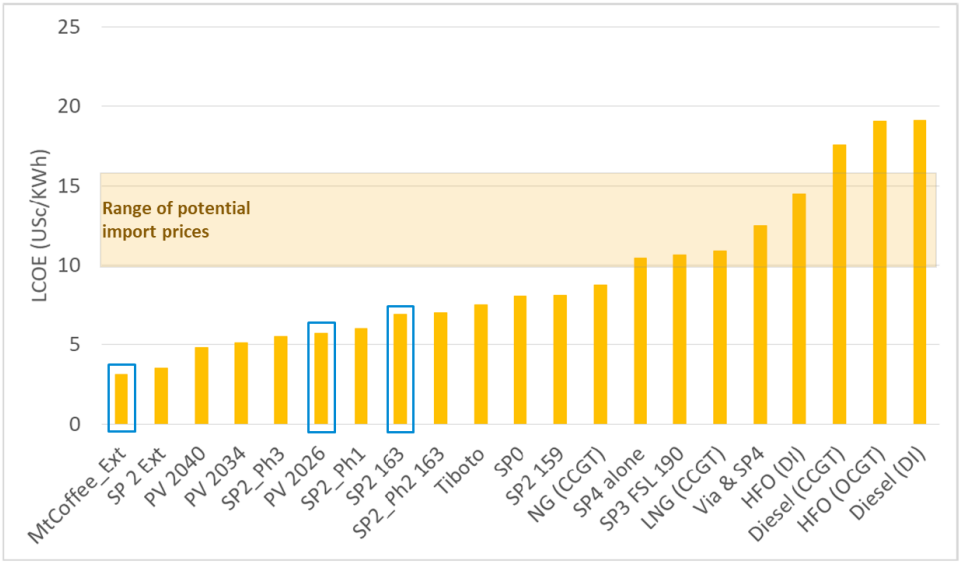
SP2 Alternatives	No. of Directly Affected Villages	Est. No. of Structures	Est. No. of Houses	Est. No. of People	Estimated Cost for Direct Impacts	Estimated Cost Land Acquisition	No. of Indirectly Affected PAPs	Estimated Cost for Indirect Impacts	Estimated Cost Access Infrastructure	Total Social Safeguards Mitigation
157.5 FSL	9	300	225-270	1,125-1,620	3.5 - 5.0 MUSD	0.5 MUSD	267-320	0.6 – 0.7 MUSD	0.4 MUSD	4.9 – 6.5 MUSD
159 FSL w 1 m flood	11	350	263-315	1,313-1,890	4.1 – 5.9 MUSD	0.6 MUSD	594-713	1.2 – 1.5 MUSD	1.0 MUSD	6.9 – 8.9 MUSD
161 FSL w 1 m flood	17	1,350	1,013-1,215	5,063-7,290	15.7 – 22.6 MUSD	0.9 MUSD	723-868	1.5 – 1.8 MUSD	1.6 MUSD	19.7 – 26.9 MUSD
163 FSL w 1 m flood	20	1,575	1,181-1,418	5,906-8,505	18.3 – 26.4 MUSD	1.0 MUSD	723-868	1.5 – 1.8 MUSD	1.6 MUSD	22.4 – 30.8 MUSD
163 FSL w 2 m flood	53	3,025	2,269-2,723	11,344-16,335	35.2 – 50.6 MUSD	2.7 MUSD	1,446-1,735	3.0 – 3.6 MUSD	3.2 MUSD	44.1 – 60.1 MUSDs

All mitigation will require careful planning and budgeting and the budgets are only high-level preliminary estimates. Recommendations for the next steps of PIP development, include a fish and fisheries monitoring program, an environmental flow study, establishment of sediment transport and water quality monitoring, and development of the terms of reference for the ESIA and RAP. Such studies are often on the critical path and should be initiated as soon as possible. Estimated environmental and social mitigation costs have been included in the investment cost for the individual hydropower projects in the analysis below.

Supply Options considered

The figure below summarizes the relative attractiveness of all generation options considered for the study – by means of the LCOEs. It is important to recognize that while the ranking of LCOEs is illustrative and informative, they do not necessarily correspond with a least cost operation of a power system that must meet daily demand in light of intermittent renewables. Accordingly, the primary basis for the recommended PIP and LCDP stem from the power system optimization in Balmorel as summarized in the section below.

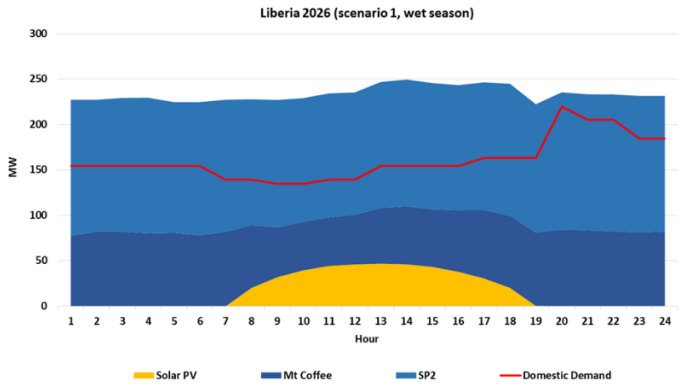
Figure 4 Ranking of LCOE's of individual candidate supply options considered in the study



Results of the power system expansion optimization (using the model Balmorel)

The optimization in Balmorel has confirmed the attractiveness of SP2, solar PV and the Mt. Coffee extension in the short- to medium-term, while highlighting the important roles for thermal, imports and eventually Via Reservoir in the long-term. Specifically, these daily generation profiles represent system operations following **an investment sequence which meets required demand at a minimum total system cost for Liberia** – and thus the required tariff for end-users. Accordingly, the results for 2026 provided key input for the determination of the PIP, and the results for 2034 and 2040 provided key inputs for the LTDP.

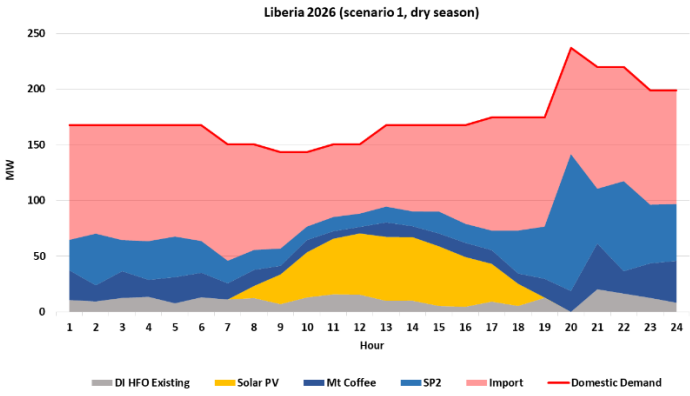
Figure 0-5 Daily demand and supply profile during a typical day in the **wet** season in **2026 once SP2 and solar has been delivered**



Some relevant observations include:

- The daily generation mix in the two figures demonstrate how hydro, solar and imports complement one another to meet demand profiles in the wet and dry seasons.
- In 2026, the least cost expansion plan for Liberia would imply a surplus in the wet season and sizeable deficit in the dry season, that the model determines is best served by imports. To the degree power trade is not available, this will likely motivate considerable more investment in HFO in Liberia to make up the difference in early years.

*Figure 0-6 Daily demand and supply profile during a typical day in the **dry** season in **2026***

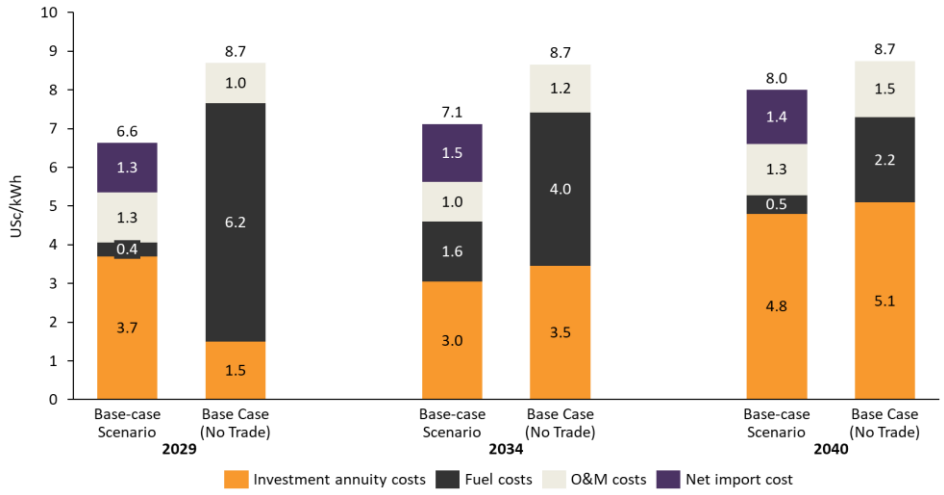


- An investment sequence whereby Via is constructed prior to SP2 and/or Mt. Coffee extension is not economically viable and would thus but a heavy cost burden on the sector.

Development of System Costs

To the degree Liberia implements both the PIP and the LTDP, the country can expect to meet growing demand, enable access expansion and industrialization at a low cost. This should of course result in a cost of supply lower than todays level. While, the reduction of system losses will undoubtedly provide the most significant system cost reductions, so will the successful implementation of the proposed least cost developments. As illustrated by the figure below, successful implementation of the PIP (including bringing losses to an acceptable 20%), the system cost is estimated at USc 6.6 per kWh, rising slightly in long-term as more expensive projects are brought online. The figure also illustrates how a lack of availability of imports will both increase system costs considerably (about 30%) and make Liberia heavily reliant upon thermal generation in the near- to medium-term.

Figure 7 Development of total system costs (supply) for Liberia with successful implementation of the PIP and LTDP, with and without power trade on the CLSG



Risk management & resilience of proposed PIP & LTDP

It is important to recognize that this exercise has been carried out to determine the least cost expansion plan to meet demand until 2040, given best knowledge and prognosis at the time of the study. No doubt, there are considerable uncertainties as to the future and thus what the optimal choices are today. These uncertainties include: T&D build out and demand growth (currently an ambitious 12% per year), actual construction costs (currently estimated within +/- 30% range), actual E&S impacts and costs, construction timelines (currently little contingency planned for), availability of import and export, etc. In this regard, the team is of the view that the step-wise (several projects) and diversified (hydro, solar and trade) nature of the PIP is consistent with a strategy to manage risks and make required adjustments as circumstances change.

Recommended immediate priorities

1. First, Liberia has no time to waste in terms of initiating planning and implementation of the next generation projects. Even in well developed countries, such levels of investment planning and financial mobilization takes time. If Liberia is not able to plan for such investments in line with this LCDP sequence, the economic costs will be significant, either in the form of power shortages or expensive supply alternatives such as heavy reliance on imported HFO.

2. Second, given the clear attractiveness of the proposed PIP (SP2, solar PV and Mt. Coffee Extension), and Liberia's projected demand growth, these projects need to be fast-tracked. The short-term alternative to these projects would again be HFO production, increased imports, constrained demand and/or power shortages, or expensive emergency power solutions.

3. Third, for the medium- to long-term, effective planning in the sector should allow for an expansion path which underpins strong economic growth, industrialization and access expansion. But, again, effective and continuous planning is essential. This will require both fast-tracking the PIP while also, and in parallel, developing plans for future investments. In particular, given the likely future role for the Via Reservoir and the magnitude of the project, continued studies of the site should be considered.

4. Finally, the potential for solar is significant, especially if the cost of batteries continue to fall. Furthermore, and especially in the short term, solar PV's complementarity with daily hydro peaking makes it particularly attractive for Liberia. Stakeholders should start analysing more closely the implications and limitations of the system's ability to absorb considerable amounts solar power and initiate a small pilot solar PV project as soon as possible.